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Geomagnetic field variations at low and high latitude during the January 10-11, 1997 magnetic cloud

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Abstract. On Jan. 10-11, 1997 a wide magnetic cloud reached the Earth triggering intense geomagnetic activity. Observations performed at low and very high latitude show that the same features appear simultaneously in correspondence to different changes in the solar wind conditions. In particular, highly polarized modes are simultaneously observed at the same discrete frequencies after the passage of the high density solar wind region following the cloud. SI's and ULF waves polarization are also examined in a wide latitudinal and longitudinal extent.

Introduction

The term "magnetic cloud" was introduced in the scientific literature by Burlaga et al. (1981) to describe a particular type of solar wind (SW) ejection. Several investigations have recently analyzed the interaction of magnetic clouds with the Earth's magnetosphere (Lepping et al., 1991; Farrugia et al., 1993a, 1993b) as well as the association between extended southward interplanetary magnetic field (IMF) intervals within magnetic clouds and great geomagnetic storms (Farrugia et al., 1996). In the present paper we conduct a study of the geomagnetic field variations associated with the passage of the Jan. 10, 1997 magnetic cloud. Simultaneous observations at a low latitude (L'Aquila, Italy; AQ) and an Antarctic station (Terra Nova Bay; TNB) show similar features despite the wide latitudinal and longitudinal separation.

Geomagnetic Effects at AQ and TNB

We used the 1 min averages of the geomagnetic field components H and D at AQ (IGRF95 geomagnetic coordinates: 36.2°N, 87.5°E; L=1.5; LT=UT+1; MLT=UT+1:40) and TNB (80.0°S, 307.7°E, LT=UT+13; MLT=UT-8:06). As discussed in other papers in this issue, on Jan. 10, 1997 the arrival of a magnetic cloud was detected from WIND at a geocentric distance of ~85 R_e in the Earth-Sun direction. In Fig. 1 the H and D components at AQ and TNB are plotted together with the interplanetary parameters observed during a time interval of 60 hours. As can be seen, on Jan. 10 at 0053 UT a shock wave was detected from WIND. It is well identified by a step increase of the SW speed (from ~380 to ~450 km/s), thermal speed (~25 to ~45 km/s), proton number density (~5 to ~15 cm^{-3}) and IMF intensity, B (~3 to ~10 nT). Then, a new SW regime appeared at ~0500 UT; at its appearance, it was characterized by extremely low density (2-3 cm^{-3}), pre-shock values of thermal speed, while B further increased to ~15 nT and became definitely southward. These features seem to mark the front boundary of the magnetic cloud in which the Earth was embedded for the following 20 hours. During this time interval B had an approximately constant value of ~15 nT and its direction smoothly rotated from southward to northward at the rear edge of the cloud. At the end of the cloud (Jan. 11, at 0054 UT) WIND detected a strong density enhancement with peak values of ~150 cm^{-3}. It was associated with a slow increase of B (up to ~20 nT), while the IMF orientation was constantly northward.

The passage of the interplanetary event triggered intense geomagnetic activity. Namely, in correspondence to the 0053 UT shock, a positive SI (which more clearly emerges at AQ in Fig. 1) was observed simultaneously (Jan. 10, 0106 UT) at both stations, with an amplitude of the H component of ~15 nT at AQ and of ~20 nT at TNB. Similarly, the strong density enhancement detected on Jan. 11, 0054 UT caused at 0118 UT a sharp SI with an amplitude of ~30 nT at AQ and ~45 nT at TNB. In both cases, the time delay (13 and 24 min, respectively) well corresponds to the transit time between WIND and Earth of the SW structures, as estimated taking into account their velocity and normal direction (Szabo, 1994). Both SI's occurred while AQ was in the nightside hemisphere and TNB in the late local magnetic afternoon. The polarization patterns (Figure 2) show at each station similar shape and orientation for both events; the different orientation in the H/D plane for the two stations is a consequence of the much greater relative importance of D at TNB (Figure 1). The sense of polarization is counterclockwise (CCW) at both stations during the first SI; during the second, at AQ the hodogram still shows a CCW rotation while at TNB the polarization is clockwise (CW). The results at AQ are consistent with those obtained at middle latitude by Wilson and Sugiura (1961).

The prolonged southward IMF produced at AQ, in the H component, the typical signatures of a geomagnetic storm with a main phase characterized by a ~100 nT decrease during a time interval of ~10 hr; as expected (McPherron, 1991), at cusp latitudes these features were less evident. During the main phase, both stations revealed a bay-like variation of the D component, accompanied also by a less evident variation of H. At TNB, D experienced a sharp change from -226 nT (at 1046 UT) to -491 nT (1104 UT) and then increased reaching -142 nT at 1123 UT. At AQ, the equal duration D variation was somewhat delayed: it occurred, indeed, between 1050 and 1126 UT and had an amplitude of ~37-40 nT. These features could be associated with the sharp SW density enhancement detected between 1033 and 1055 UT. Similar variations in association

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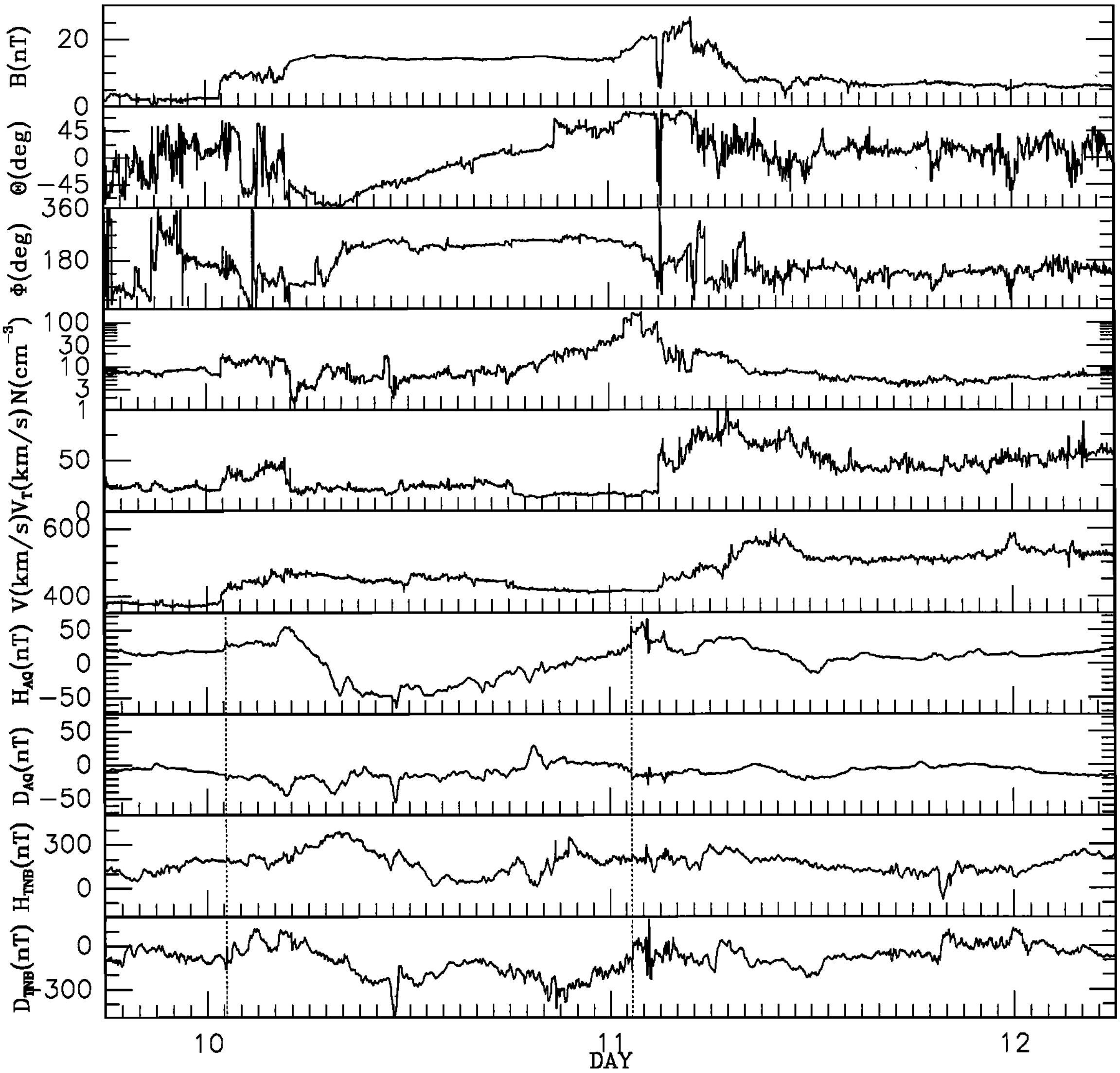

Figure 1. Interplanetary magnetic field, plasma parameters and geomagnetic field components at AQ and TNB from Jan. 9, 1800 UT until Jan. 12, 0600 UT. Dashed lines indicate the SI's discussed in the text.

with SW pressure enhancements have been observed at mid latitude by Luhr and Blawert (1994), who also proposed an interpretation in terms of field aligned current systems.

In Fig. 3 we show the dynamic spectra between 0.8 and 5 mHz, as computed following the frequency-time analysis method suggested by Dziewonski et al. (1969), with 50 filters centered on logarithmically equispaced frequencies and the parameter α=200 characterizing the bandwidth of each filter. As can be seen, there is a strong correspondence between the two stations in the time sequence of the power enhancements which seem related to the different SW pressure variations (at ~0100, 0500, 0700, 1030 UT on Jan. 10 in Fig. 1). In particular, the greatest wave activity detected after 0100 UT on Jan. 11 corresponds to the arrival of the high density SW region. At TNB this activity is preceded, around local magnetic noon, by a broad band signal intensification which is typical of the near cusp region (McHarg et al., 1995).

The power spectra (computed by means of the maximum entropy method at order 30 of the prediction error filter) corresponding to the major power intensification (Jan. 11, 0000-0400 UT, Figure 4) confirm that at TNB, over the whole frequency range, D has a much higher power content than H (Villante et al., 1997). Major peaks clearly emerge on H and D approximately at the same frequencies, namely 1, 1.4, 1.8 and 2.2 (TNB) - 2.4 (AQ) mHz. At both stations highly polarized events (with a polarization ratio greater than 90%) correspond to these frequencies; moreover, the highest coherence (>0.9) between the two stations for both components corresponds to the 1.8 mHz mode. Figure 5 shows the corresponding filtered data. As can be seen, at both stations there is a strong signal intensification after 0100 UT with maximum values between 0200 and 0230 UT. At AQ the polarization pattern is always CCW, while several reversals of the polarization pattern are observed at TNB. Within the limits of the present investigation, the emerging overview at both stations appears consistent with the MLT and latitude dependence of the polarization pattern proposed by Samson (1972; solid and light bars in Figure 5 identify the expected CW and CCW polarizations, respectively; in the southern hemisphere the sense of polarization has been reversed).

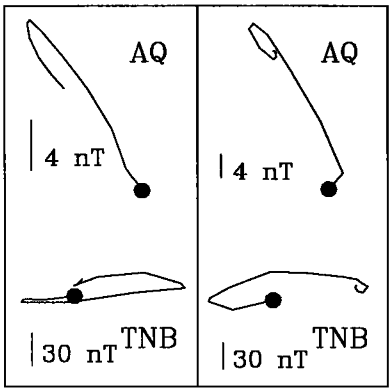

Figure 2. Polarization plots of the SI's at the two stations. Left: 0100-0115 UT on Jan. 10; right: 0115-0131 UT on Jan. 11. Dots indicate the initial points.

Summary and Conclusions

An analysis of the geomagnetic field variations observed at very high and low latitude in opposite hemispheres during the passage of the Jan. 10-11, 1997 magnetic cloud shows that the major SW pressure variations were followed by intense geomagnetic disturbances.

During the major intensification of the fluctuation activity, the lowest frequency modes appear at both stations approximately at the same discrete frequencies for both components with a high coherence between stations. The observed features can be tentatively interpreted in terms of compressional oscillations of the whole magnetosphere generated by the strong SW pressure pulse (Walker et al., 1992). Some evidence for such global oscillations has already been proposed in previous statistical studies of ULF fluctuations at TNB (Villante et al., 1997) and AQ (Francia and Villante, 1997). Moreover, the polarization pattern which emerges from a peculiar analysis of the most coherent mode (1.8 mHz) can be considered consistent with that one proposed by Samson (1972, Figure 13), who found that the polarization of waves with frequency lower than 4 mHz exhibits a latitude dependence as well as a switch around the local noon. This pattern can be interpreted in terms of waves propagating westward in the morning (corresponding to CCW polarization in the northern hemisphere, as actually observed at AQ) and eastward in the afternoon, as expected for any magnetospheric excitation driven by the SW. On the other hand, when the effects of the field line resonance are taken into account (Southwood, 1974; Chen and Hasegawa, 1974a,b), it emerges at high latitudes a complex pattern in which several polarization reversals might be expected at different MLT (as observed at TNB).

Two sharp SI's at both stations were associated with the SW discontinuities at the edges of the cloud. When interpreted in terms of hydromagnetic waves driven by external sources impinging the dayside magnetosphere (Araki and Allen, 1982), their polarization pattern can be also considered tentatively consistent with the present scenario, in that the CCW polarizations observed at AQ for both SI's and at TNB for the first one are those expected at the corresponding MLT. In this scheme, the CW polarization observed at TNB during the second SI would imply a shift of the demarcation line between opposite polarizations to latitudes higher than TNB, due to the extreme magnetospheric compression (according to

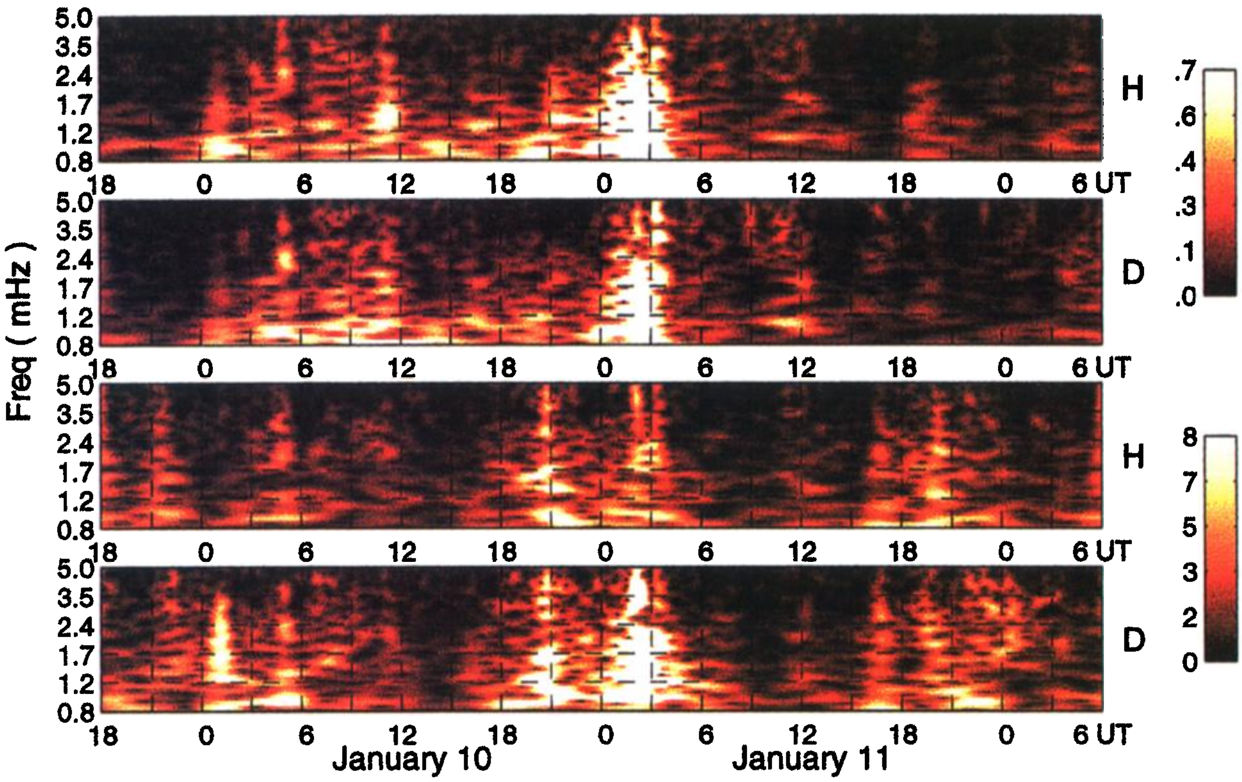

Figure 3. Dynamic power spectra of the H and D components at AQ (upper panels) and TNB (lower panels).

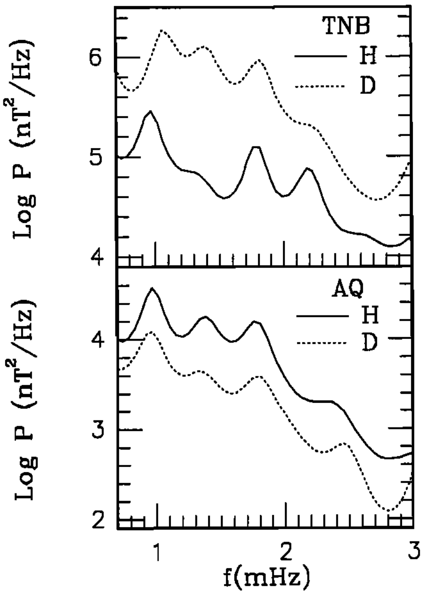

Figure 4. Jan. 11, 0000-0400 UT power spectra.

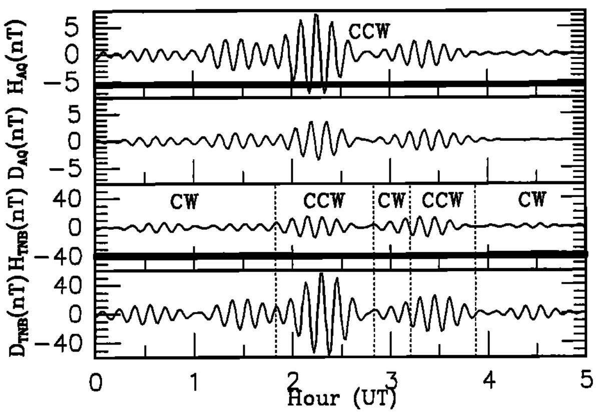

Figure 5. The 1.8 mHz filtered signals on Jan. 11, 0000-0500 UT. 'CW' and 'CCW' indicate the observed polarization, while solid and light bars indicate respectively the time intervals in which, according to Samson (1972), CW or CCW polarization is expected.

Carlowicz, 1997, the magnetopause was compressed inside geosynchronous orbit). On the other hand, as discussed by Araki and Allen (1982), at high latitude the polarization of SI's is not clearly defined.

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